

# Accelerating the development of electric propulsion systems for aviation through building a digital ecosystem

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## Kurzfassung

Eine signifikante Reduzierung der Treibhausgasemissionen im Luftverkehr kann nur durch den Einsatz alternativer Antriebssysteme erreicht werden. Ihre Anwendung erfordert eine Analyse des gesamten Ökosystems, einschließlich der Luftverkehrsinfrastruktur, Sicherheitsaspekte, Zertifizierung und Wartung von Flugzeugen mit neuen Antriebssystemen. Im Rahmen des DIREKT-Projekts entwickelt CHESCO einen digitalen Zwilling des (hybrid-)elektrischen Flugzeug-Ökosystems, der die Analyse verschiedener Aspekte im Zusammenhang mit alternativen Antriebssystemen ermöglicht. Derzeit werden innerhalb dieses Ökosystems drei Modelle entwickelt: Betriebs-, Batterie- und alternatives Antriebssystem. Das erste Modell analysiert die Auswirkungen des neuen Antriebssystems auf den Flugbetrieb, während das Batteriemodell die Simulation und Analyse von Änderungen der Batterieparameter während des Einsatzes ermöglicht. Das Modell für alternative Antriebssysteme konzentriert sich auf die Analyse der erforderlichen Betriebsparameter eines Flugzeugs mit einem neuen Antriebssystem. Die Verwendung eines digitalen Zwillings des (hybrid-)elektrischen Flugzeug-Ökosystems ermöglicht eine eingehende Analyse verschiedener Aspekte der Anwendung des neuen Antriebssystems sowie eine Beschleunigung seines Entwicklungsprozesses, wodurch die Projektkosten gesenkt werden.

## Abstract

A significant reduction in greenhouse gas emissions in aviation can only be achieved through the use of alternative propulsion systems. Their application requires an analysis of the entire ecosystem, including aviation infrastructure, safety aspects, certification and maintenance of aircraft with new propulsion systems. In the DIREKT project, CHESCO is developing a Digital Twin of the (hybrid)-electric aircraft ecosystem that allows for the analysis of various aspects related to alternative propulsion systems. Three models are currently being developed within this ecosystem: operational, battery and alternative propulsion system. The first model analyses the impact of the new propulsion system on flight operations, while the battery model allows for simulation and analysis of changes in battery parameters during use. The alternative propulsion system model focuses on analysing the required operating parameters of an aircraft with a new propulsion system. The use of a Digital Twin of the (hybrid)-electric aircraft ecosystem allows for an in-depth analysis of various aspects of the new propulsion system's application, as well as accelerating its development process, thereby reducing project costs.

## 1 Introduction

Aviation is responsible for approximately 3% of global CO<sub>2</sub> emissions, which are the only ones that occur at altitudes. Due to the high energy demand needed for aircraft to fly and the predicted increase in the number of flight operations in the coming years, the decarbonisation of aviation is crucial to halting climate change [1].

The greatest impact on reducing greenhouse gas emissions from aviation would be achieved using new, alternative propulsion systems: all-electric, hybrid-electric and electric based on hydrogen fuel cells. However, their use requires a broader view of the entire aviation ecosystem: adaptation of airport infrastructure, safety, ensuring sufficient electricity for charging, changes in the design and maintenance of aircraft with such propulsion systems, and battery recycling.

An additional aspect that should be considered when designing a sustainable aviation ecosystem is the current level of development and pace of advancement of subsystems that make up alternative propulsion systems. The develop-

ing ecosystem must be able to consider the changing parameters of these subsystems. The current level of technology allows for the use of alternative propulsion systems in smaller aircraft flying on short regional routes: electric in GA aircraft and hybrid -electric in the segment of smaller commercial aircraft, e.g. the DHC-8 family [2].

At CHESCO, the foundations for research and development of advanced electric and hybrid propulsion systems for aviation are created. The setup of capabilities – from design through manufacturing towards test and verification are key for achieving this. At same time a thorough understanding of all stakeholders and boundary conditions is important – data from all aspects of the product lifecycle are required to understand the to be built ecosystem (Fig. 1). CHESCO focuses on building the manufacturing and testing capabilities, with the digital process chains connecting the elements of the product lifecycle. Through understanding of the aviation ecosystem, through a thorough stakeholder analysis - and through gathering of actual data – and generic data within the aerospace landscape we are building an ecosystem which will help us and our partners to understand, what technologies are required, how to achieve

airworthiness for sustainable propulsion systems and how a business model could be achieved around the various aspects of electrified aviation.

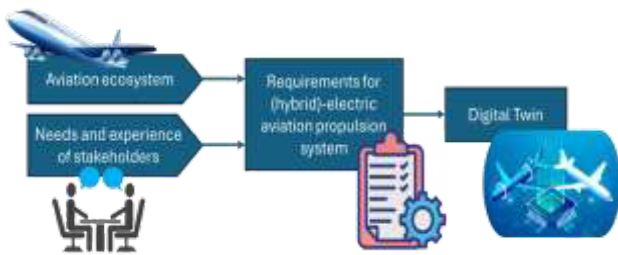


Figure 1. CHESCO's approach to creating a digital twin

## 2 Sustainable aviation ecosystem

The use of alternative propulsion systems in aviation involves several changes to the existing ecosystem. These adjustments are related to the emergence of new airworthiness requirements, stakeholders' needs and propulsion capabilities. One of the main changes is the adaptation of the airport infrastructure to the requirements of alternative propulsion aircraft: it needs to ensure that aircraft batteries can be recharged, required procedures need to be developed accordingly, from where the electricity will be drawn and how it will be produced. The performance of alternatively propelled aircraft is more limited and fewer adapted airports to (hybrid)-electric propulsion introduce a new level of complexity in the use of such aeroplanes. Access to aerodromes that allow full service of alternatively-powered aircraft influences the planning of flight operations of these aircraft, e.g. by scheduling longer layovers at such an aerodrome to recharge the batteries to the required level for subsequent flights from an airport that does not have this capability. Knowing the parameters of the planned flight operations also allows a tailor-made approach to alternative propulsion design in terms of providing the required range and power by selecting the appropriate battery parameters and thus adapting the airframe to it.

Part of the LuFo funded research project DIREKT (Digitaler Lebenszyklus hybrid-elektrischer Antriebssysteme) is the development of Digital Twin of the (hybrid)-electric aircraft ecosystem with using Model-Based Systems Engineering (MBSE) methodology to develop the relevant models describing different aspects of the alternatively-powered aeroplane. Currently, the following models are being developed: operational, battery and alternative propulsion systems.

### 2.1 Operational model

The operational model (Fig. 2) will simulate the flight of a (hybrid) electric aircraft, considering the main parameters of the ecosystem. The model will allow the simulation and analysis of various operational scenarios, including the impact of alternative propulsion on planning longer layovers at airports with the necessary battery charging infrastructure and the analysis of maximum passenger numbers for

aircraft upgraded to the new propulsion system. In addition, the model will have the ability to compare different battery types for the aircraft under analysis and its operations. It will also measure the aircraft's total CO<sub>2</sub> emissions in relation to a defined energy mix for a region or country needed to generate the required amount of electricity to charge the aircraft's batteries. The propulsion system model will be used to analyse the required propulsion parameters, to simulate the interactions between systems and subsystems and to assist manufacturers in designing aircraft with the new propulsion system. The model will also enable the selection of an appropriate operating strategy for the hybrid-electric propulsion system and its optimisation. An in-depth analysis of the propulsion system at an early design stage will reduce errors in the next phases of aircraft development.

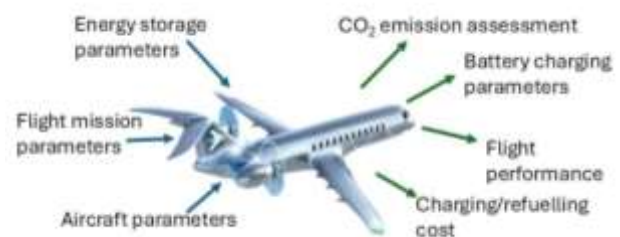


Figure 2. Overview of the operational model parameters: Inputs and outputs

This model also allows for a trade study to be conducted regarding the degree of hybridisation of the propulsion system of a selected aircraft (Fig. 3).

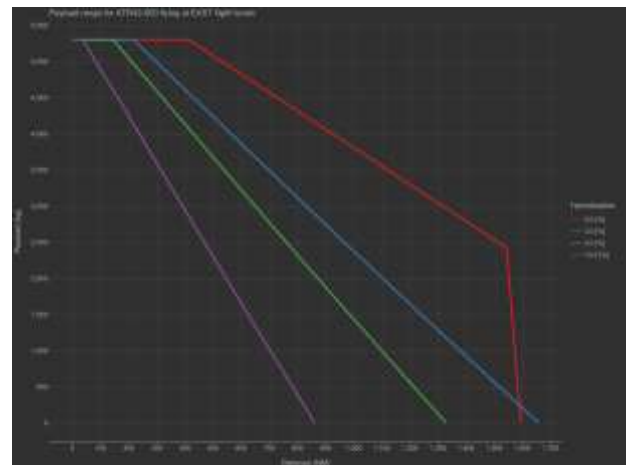
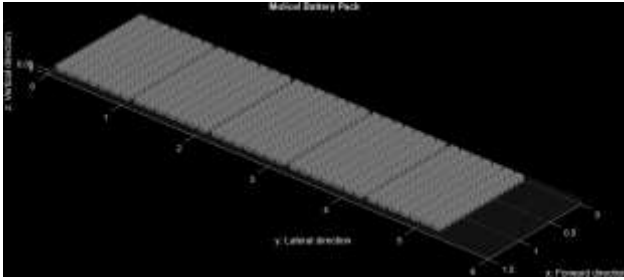


Figure 3. Payload range analysis for ATR 42-600 with different degree of hybridisation: red line- 0%, blue line- 3%, green line- 5%, purple line- 10%

### 2.2 Battery model

The battery model is developed using the built-in MATLAB application 'Battery Builder'. This application allows for individual design of battery packs based on actual cells from various manufacturers or cells with user-defined parameters. The battery model also simulates the thermal behaviour of such a battery pack. Figure 4 shows the battery layout, and Table 1 shows its main parameters.

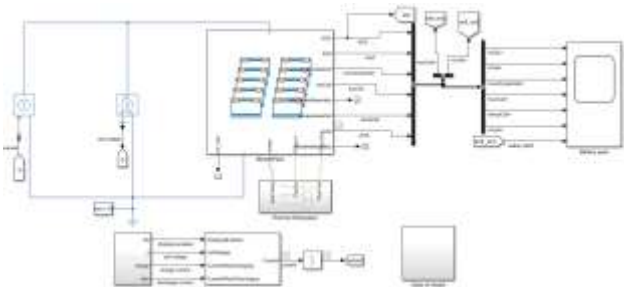


**Figure 4.** Molicel battery pack designed in Battery Builder App for battery simulation model

Battery parameters	
Cell	Molicel INR21700-P45B
Capacity	252 Ah
Energy	113.4 kWh
Weight	490 kg
Configuration	125s56p

**Table 1.** Battery parameters

The simulation model (Fig. 5) of the battery analyses its performance during operation (discharging) and charging, number of possible operating cycles, and battery State of Health (SOH). The function of this model is not only comprehensive battery analysis but also support in the certification process and reduction of the number of physical tests, which contributes to lower project costs.



**Figure 5.** Battery model developed in MATLAB/Simulink software

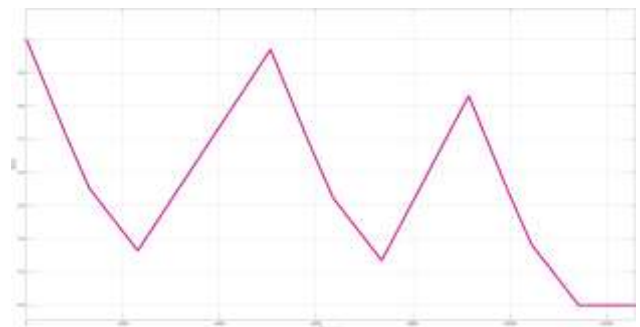
The battery simulation model allows for the simulation of various battery charging and discharging scenarios, enabling the creation of a diverse flight schedule for the aircraft. With the help of Stateflow, which enables the creation of control logic for a simulation model, a scenario was developed that allows battery charging to be defined in various ways. The following scenarios were developed:

- charging the battery to a specific level (e.g. to 97%),
- charging the battery for a specific period of time (e.g. 30 minutes).

The first is used to determine the time required between flights to reach the required battery charge level. The purpose of the second charging scenario is to check the level to which the battery will be charged during limited downtime between flights. In both scenarios, the batteries are

charged using the CC-CV (Constant Current-Constant Voltage) method.

Battery charging and discharging is characterised by electric current, which is defined by the user. This makes it possible to simulate chargers with different power ratings. For example, a flight mission was created for a Tecnam P2006T aircraft virtually retrofitted with an electric propulsion system, which included three flights of 100 km each. Between the first and second flights, the aircraft's batteries were charged to 97% (charging current 200 A, charging time 46 minutes). For the second charge, the aircraft was charged for 30 minutes on a charger with a charging current of 250 A. As a result, it reached 83.10% battery charge level. The simulation results are shown in Fig. 6 and 7.



**Figure 6.** Battery State of Charge during the simulated flight mission



**Figure 7.** Battery State of Health during the simulated flight mission

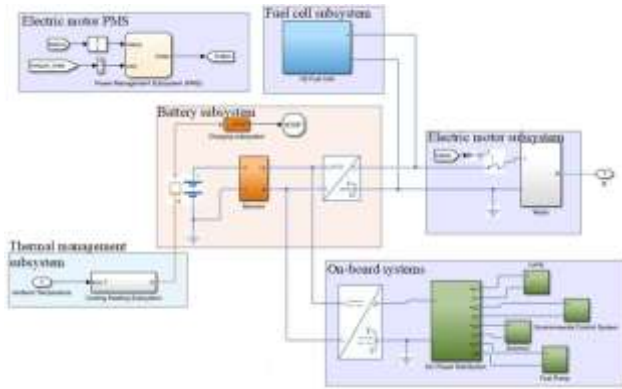
### 2.3 Alternative propulsion system model

The above models are supplemented by an alternative propulsion system model (Fig. 8) developed in MATLAB/Simulink software, which allows for the estimation of the required operating parameters of the main subsystems of the propulsion system. This model was used to select the battery parameters for the electric Tecnam P2006T, the simulation results of which are presented in section 2.2.

The developed model allows for simulations of four types of alternative propulsion systems:

- all-electric (battery only)
- series hybrid-electric
- parallel hybrid-electric
- electric based on hydrogen fuel cells.

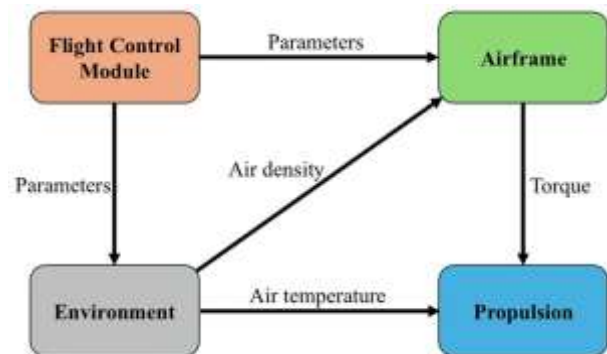
The application of this model is limited only to GA aircraft.



**Figure 8.** Alternative propulsion system model

The simulation model of alternative propulsion system (Fig. 9) consists of four main modules: flight control module, environment, airframe and propulsion. The flight control module plays the role of the pilot in the model and manages the flight mission parameters during the simulation. For each type of alternative propulsion system, the flight control module is adjusted accordingly, due to the different or additional parameters that characterise the propulsion system. Parameters from the flight control module are passed to the environment and airframe modules. The environment module is used to calculate the parameters of the Earth's atmosphere in which the aircraft is moving. For the simulation models developed, it provides values for temperature and air density as a function of flight altitude. The task of the airframe module is to calculate the required torque that should be produced by the propulsion system. To determine it, the airframe module uses flight data from the flight control module, the aerodynamic characteristics of the aircraft and the air density depending on the altitude at which the aircraft is at any given time during the simulation from the environment module. From these, the four main forces acting on the aircraft are calculated: weight, thrust, lift and drag. The last module in the simulation model developed is propulsion, which represents both the propulsion system and energy storage. It is used to determine the relevant operating parameters of the main subsystems of the propulsion and energy storage system. This is achieved by using a backward approach that causes the propulsion module to be "forced" by the airframe module to produce the required torque, affecting the energy consumption of the electric motor and/or combustion engine. The definition of the required operating parameters of the main subsystems of the alternative propulsion system allows for example the selection of commercially available subsystems, while also enabling the determination of the weight of the new propulsion system and the size of the main subsystems. In this way, the model can support the design process of an aircraft with alternative propulsion. System models for propulsion provide a deeper understanding of both existing and newly designed systems. Their application in the system design process improves decision-making by enabling virtual testing and evaluation

across various operational scenarios, reducing potential errors in the system and, in turn, minimising the need for physical prototypes and experiments. This results in a more efficient development process, along with reduced project costs.



**Figure 9.** General diagram of an alternative propulsion system model

### 3 Summary

The digital environment CHESCO is developing enables the integration of external models, such as surrogate models, provided by stakeholders, thereby strengthening collaboration and jointly deepening expertise in the field of (hybrid) electric aircraft propulsion systems.

CHESCO's digital capabilities in creating an electrified aviation ecosystem are complemented by test stands being built for its main components, such as electric motors. This will allow to fine-tune simulation models and test the developed components.

Advanced research currently being conducted at CHESCO, along with growing and essential capabilities for data collection and utilisation throughout the research cycle and product life cycle, aim to create a powerful digital ecosystem that will then be used to enable choices regarding the industrialisation of electric aviation.

### 4 Literature

- [1] Stiebe, M. Accelerating Sustainable Electric General Aviation with Fast-Charging Networks at Regional Airfields: Opportunities and Challenges. *World Electr. Veh. J.* 2025, 16, 118. <https://doi.org/10.3390/wevj16030118>.
- [2] Peciak, M.; Skarka, W. Assessment of the Potential of Electric Propulsion for General Aviation Using Model-Based System Engineering (MBSE) Methodology. *Aerospace* 2022, 9, 74. <https://doi.org/10.3390/aerospace9020074>.